OAK RIDGE National Laboratory

Preliminary MRA Backbone Structural Analysis

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U.S. DEPARTMENT OF ENERGY

MRA Backbone Structural Analysis

- A preliminary stress analysis was done for the three lower stainless steel backbone sections without Moderator Vessels
- The principal result of concern was displacements which could affect moderator location and a limit of 0.5 mm at the center of the mounting surfaces for the reflector vessels was desired
- A full CFD analysis by Min-Tsung Kao had been done and a data file for the temperatures in the region of interest was provided
- Analysis was done for 5 bar MWAP for the water and vacuum in the core vessel. A load case was also done for a failed moderator boundary with 2 bar pressure on the internal vacuum boundary

Abaqus model

Model and Input file

- Model: MRA_backbone_1.cae
- Input file: MRA_backbone1_PTPb.inp
- Only material in model was 316L SS

Abaqus material input data – bi-linear elastic-plastic model*

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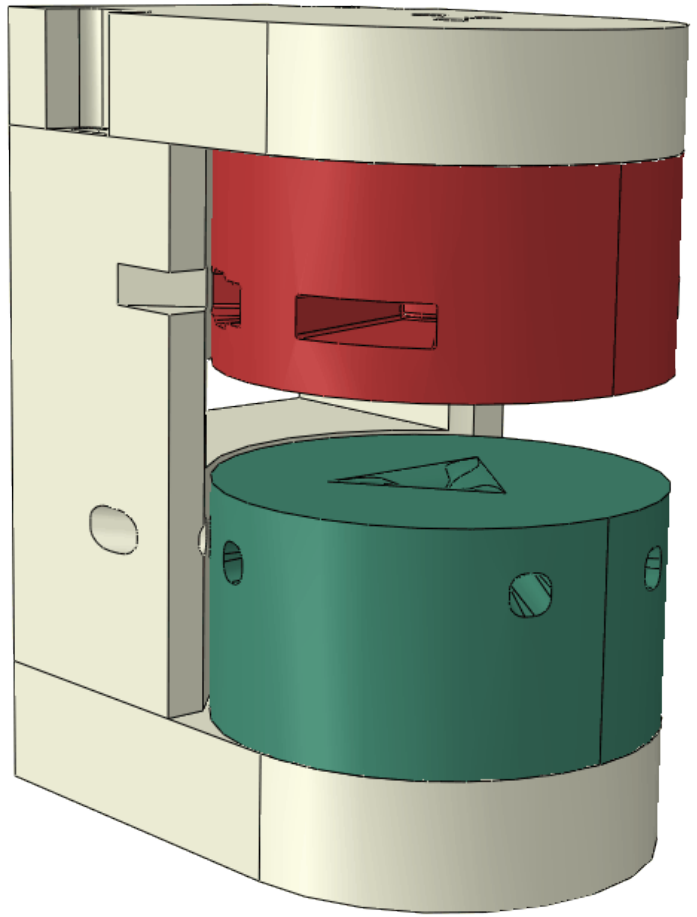
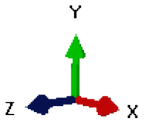
** MATERIALS
**
*Material, name=SS3161
*Densit
7969.,
*Elastic
 1.95e+11, 0.27
*Expansion, zero=20.
 1.61e-05,
*Plastic
  2.5e+08,     0.
 2.55e+08, 0.005
**
```

- ISRN LUTFD2/TFHF-19/5234-SE(1-71)
- **Material characterization of 316L**
  Master's Dissertation by
  Pardis Adibi
  and
  Rita Iteka

Lower Backbone with Moderator Reflector Vessels

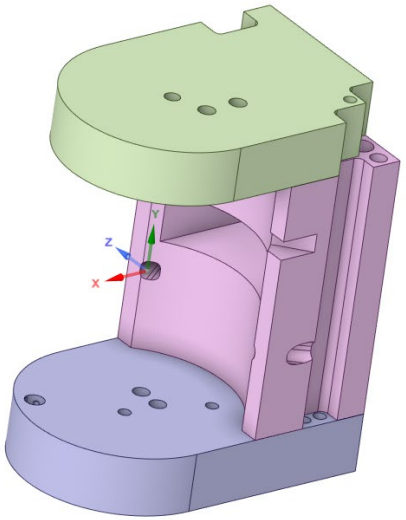


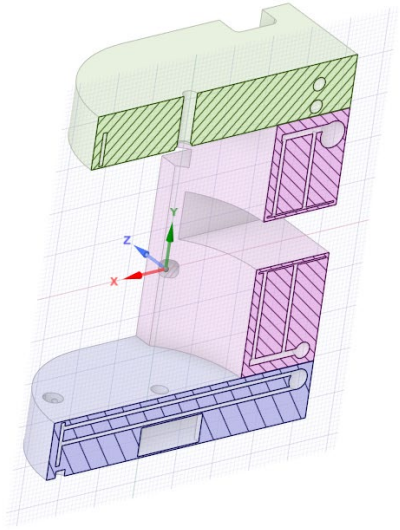


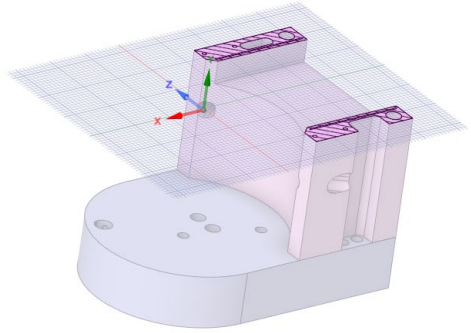
Assembly showing moderator reflector vessels alignment

Backbone SpaceClaim Model Section views

Assembly	Z=0 section	Y=0 section

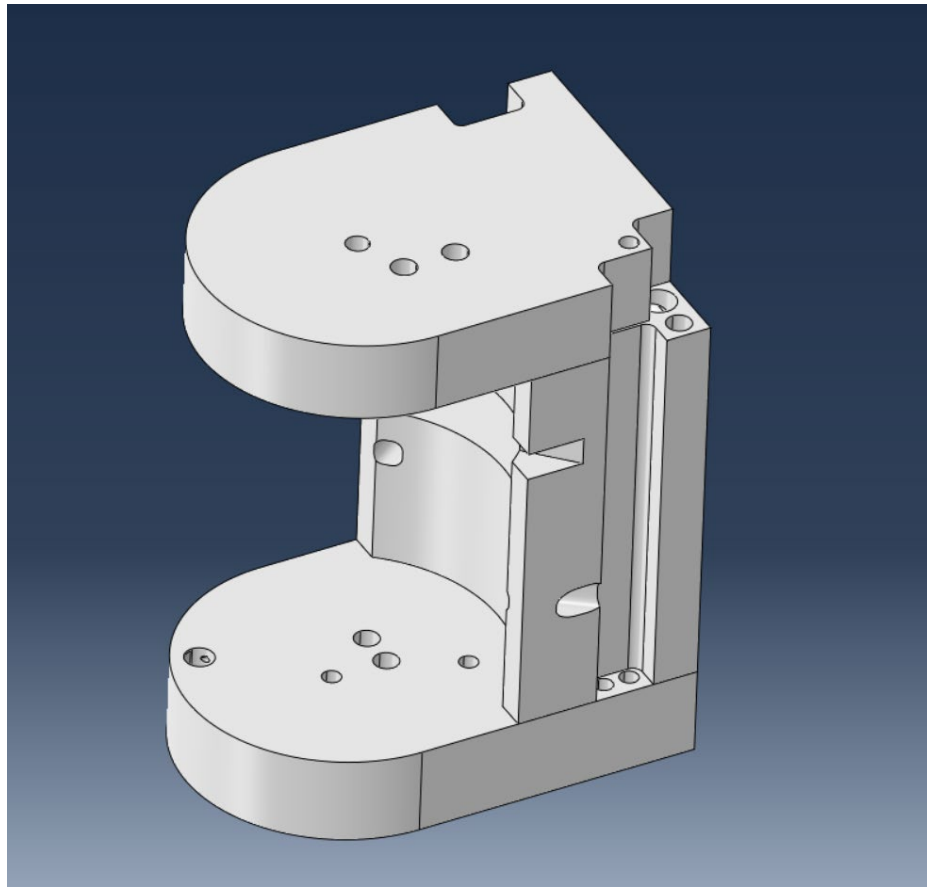




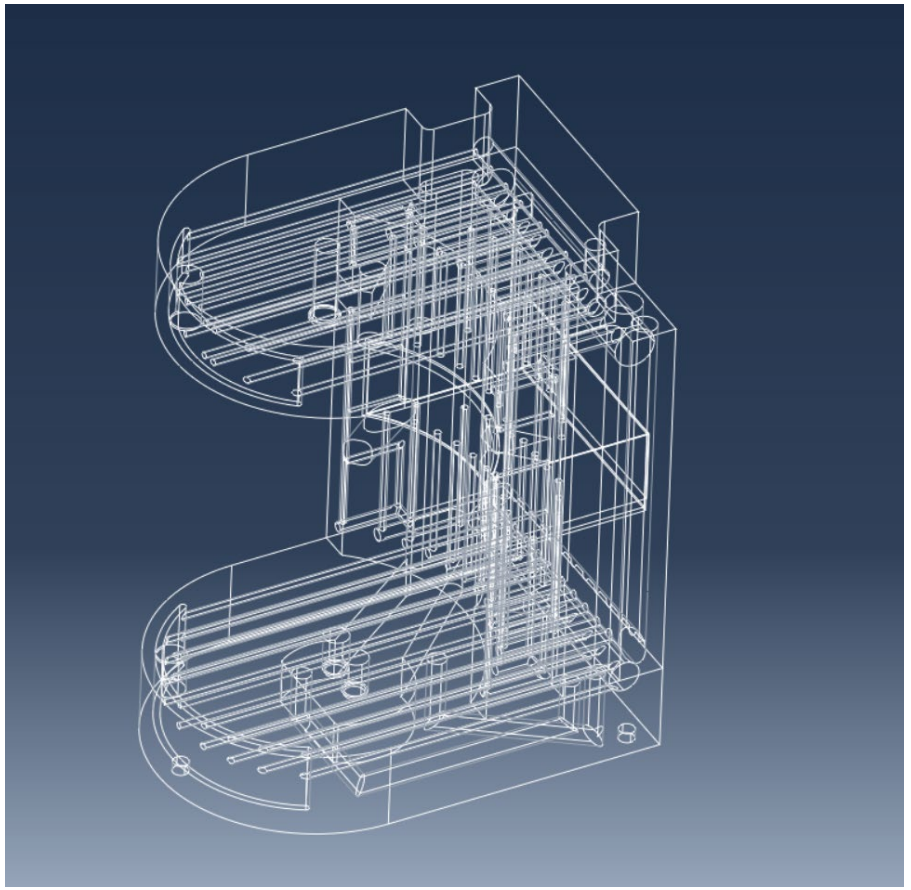


Abaqus Model with all 3 parts merged

Full model

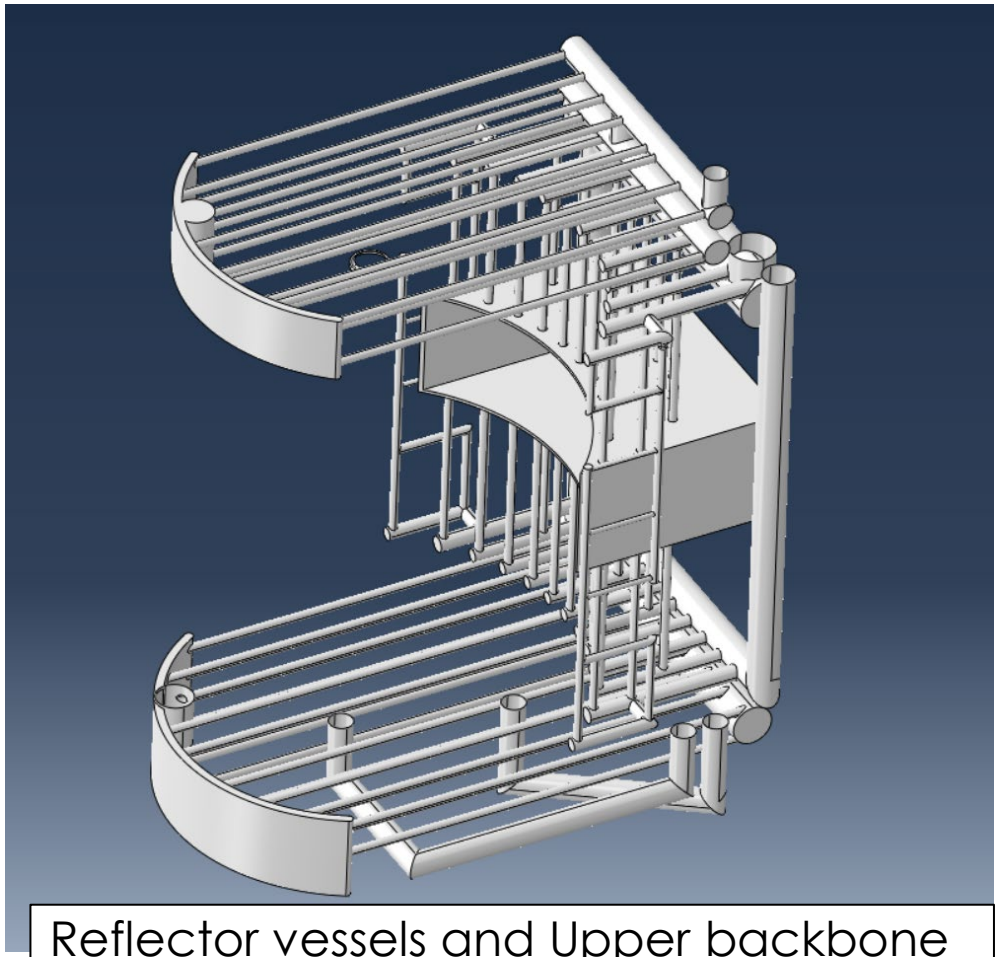


Wire Frame view showing internal passages



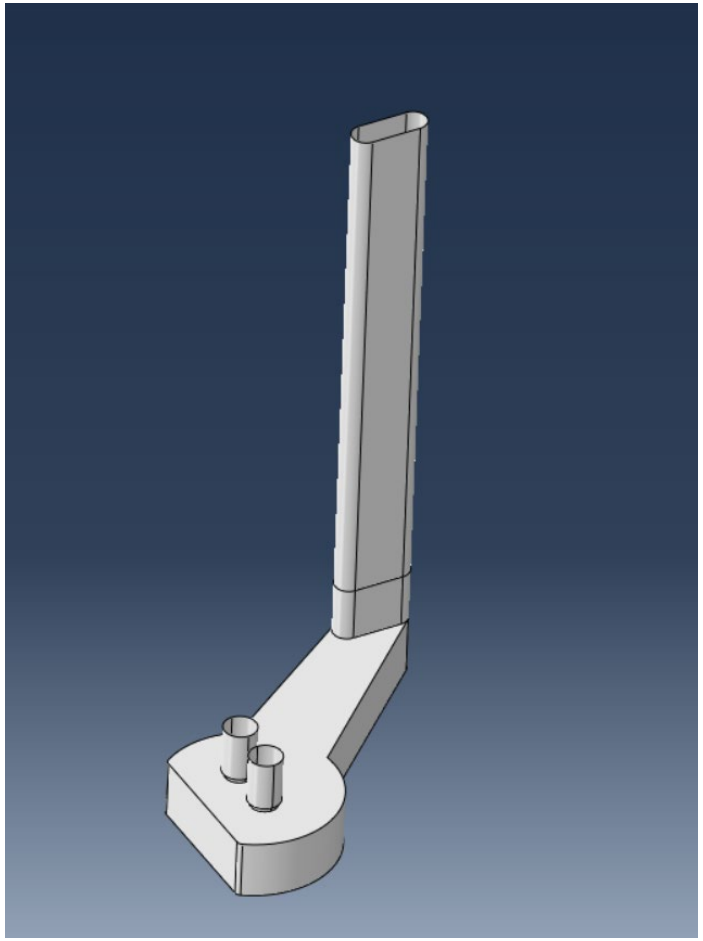
Pressure boundary surfaces

5 Bar water surfaces



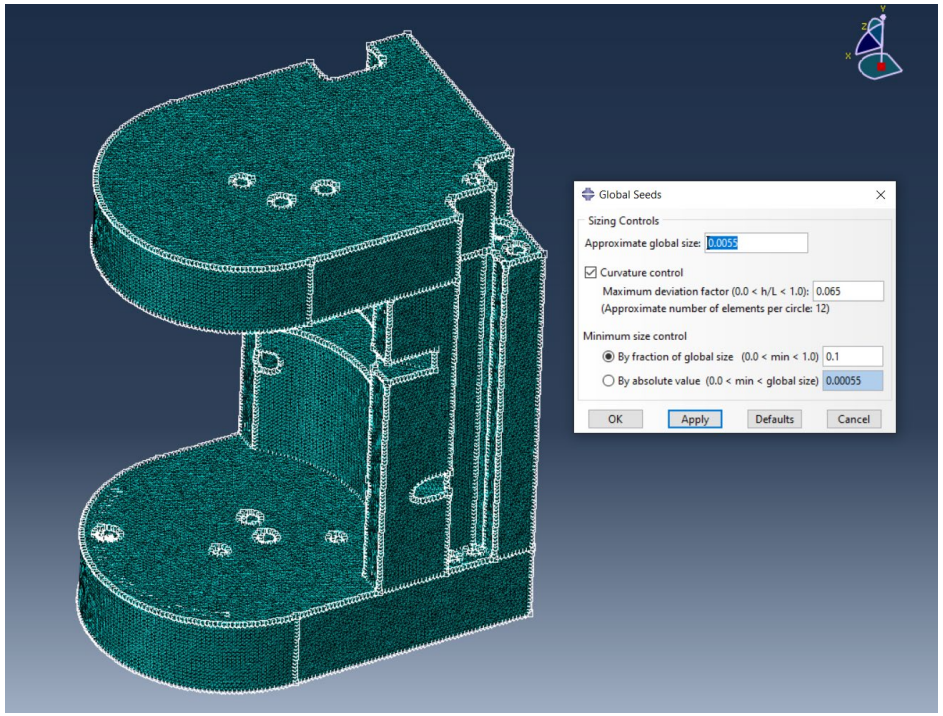
Reflector vessels and Upper backbone not included in the model so some pressure boundaries are not closed

Vacuum or 2 Bar Surface



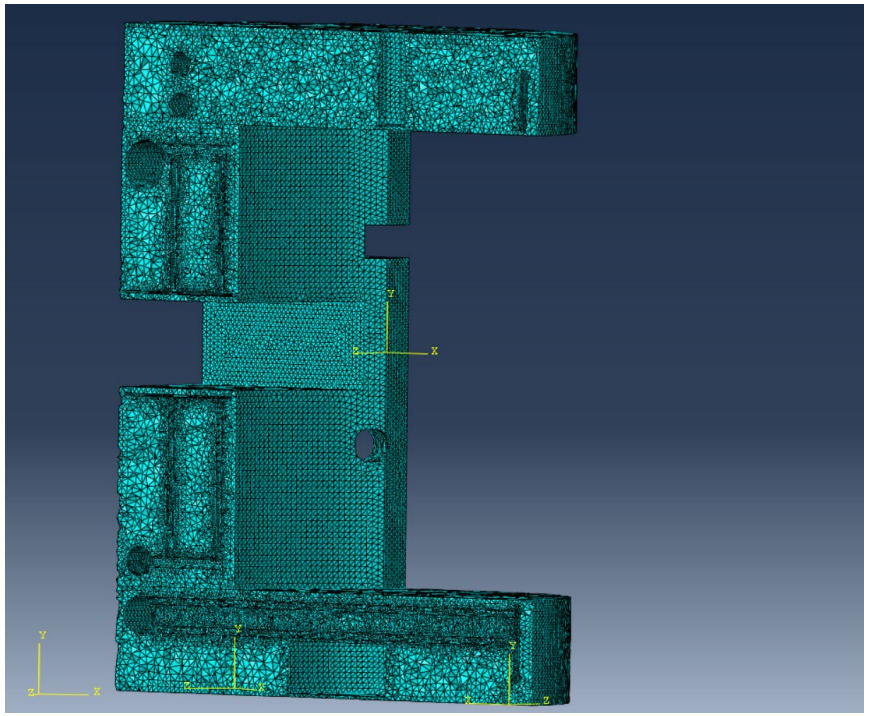
Model Mesh with C3D10 Tet elements

Nominal 5.5 mm size with 12 elements around circles

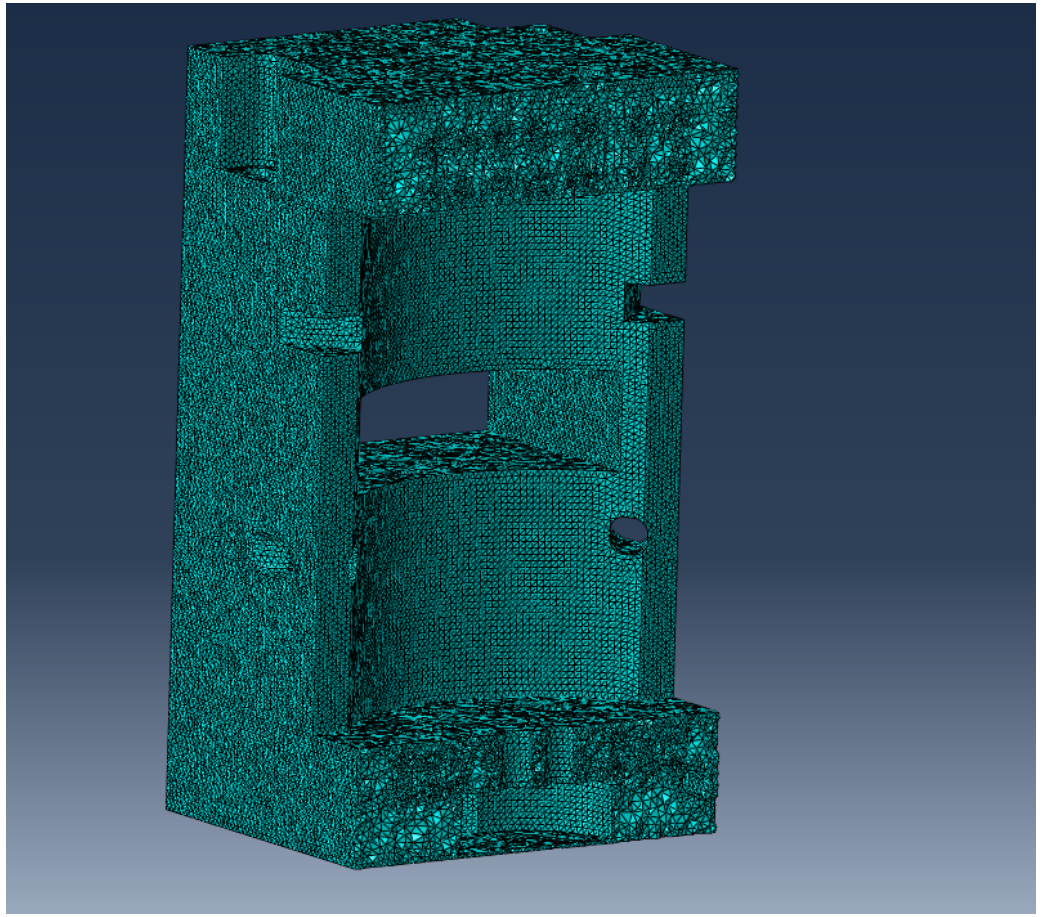


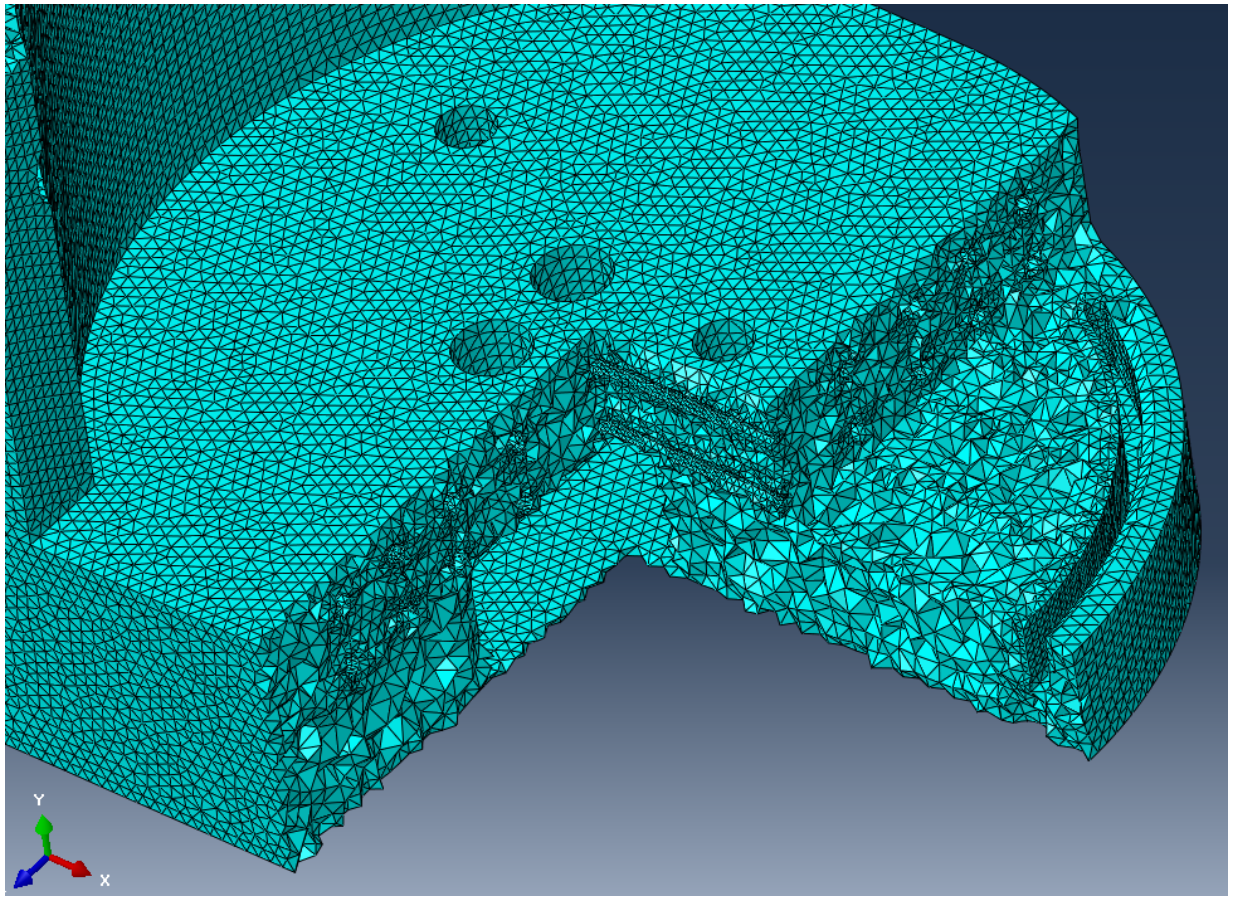
Total 3,731,555 elements

Cut near Z=0 plane



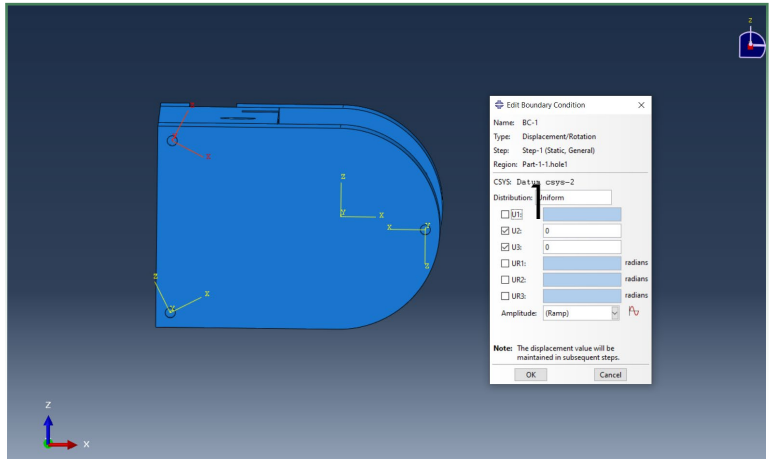
Mesh model Cut Views



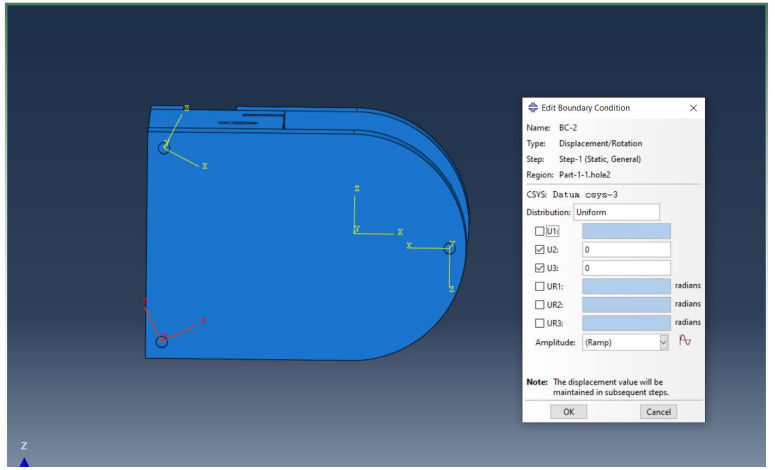


Boundary Conditions

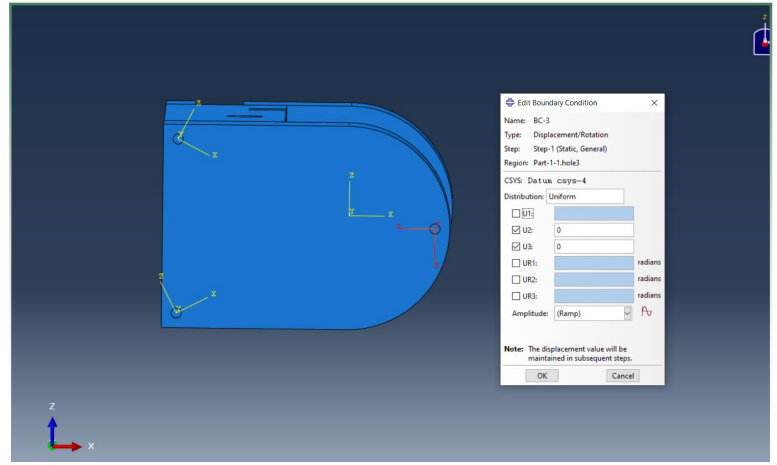
Hole 1 node constraint



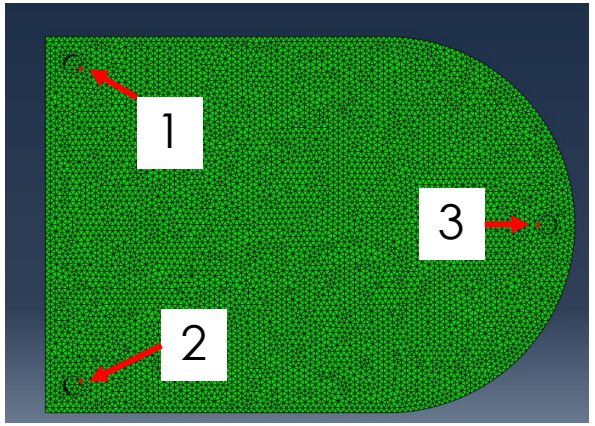
Hole 2 node constraint



Hole 3 node constraint



- Boundary condition to simulate "V" groove restraint on pins in holes to force displacement in direction of central axis
- Fixed vertically at the 3 nodes
- Applied to one node on bottom surface of each hole



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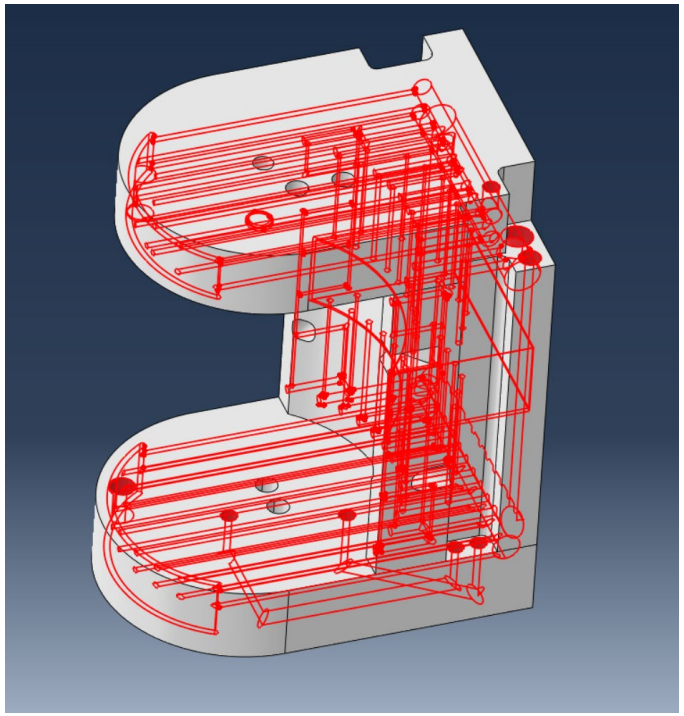
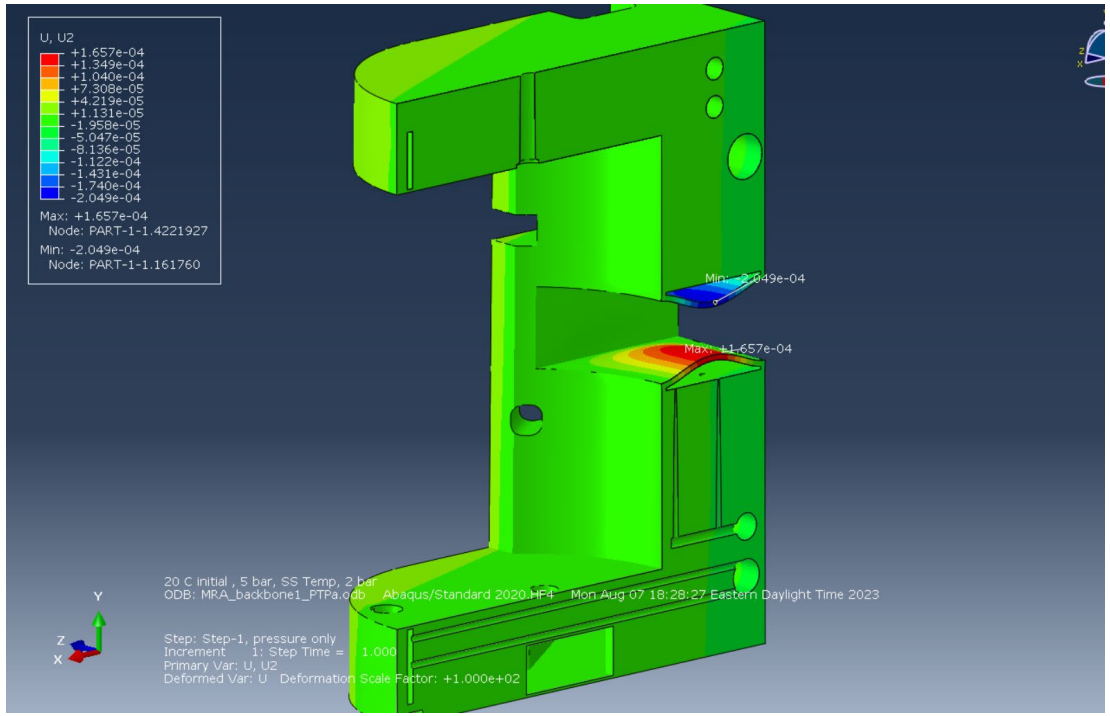
Results with 5 bar pressure and all nodes at reference temperature of 20 C

Assembly with 5 bar load applied

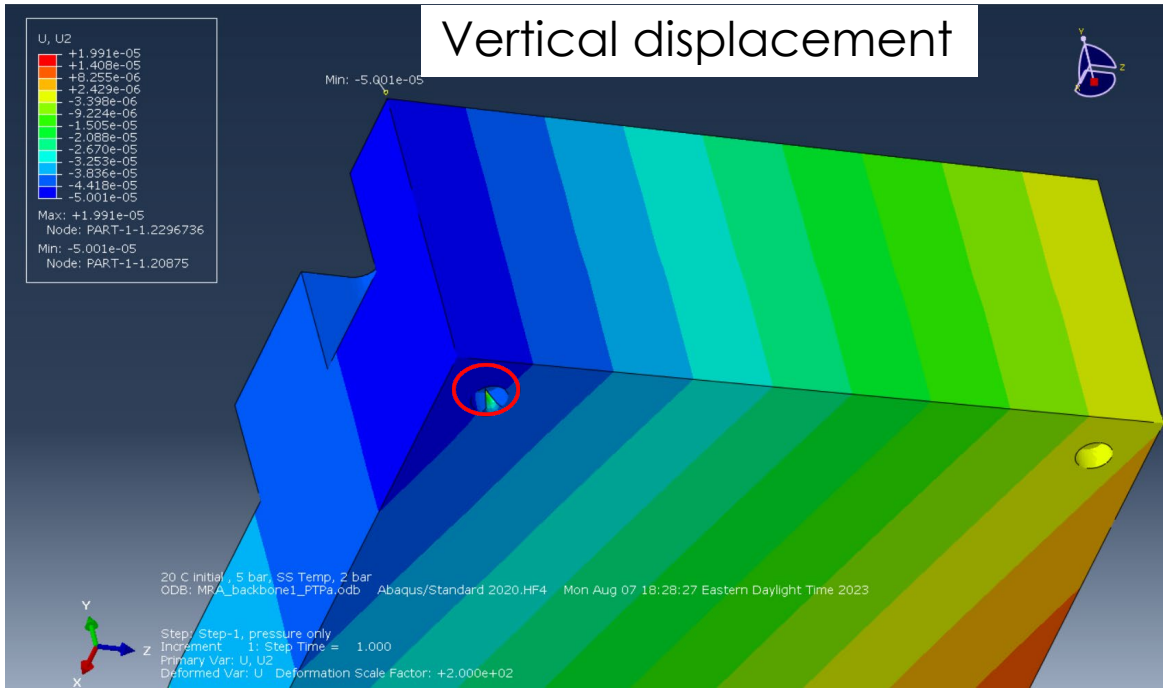


Vertical displacement - peak ~ 0.2 mm on thin walls by Proton Beam channels

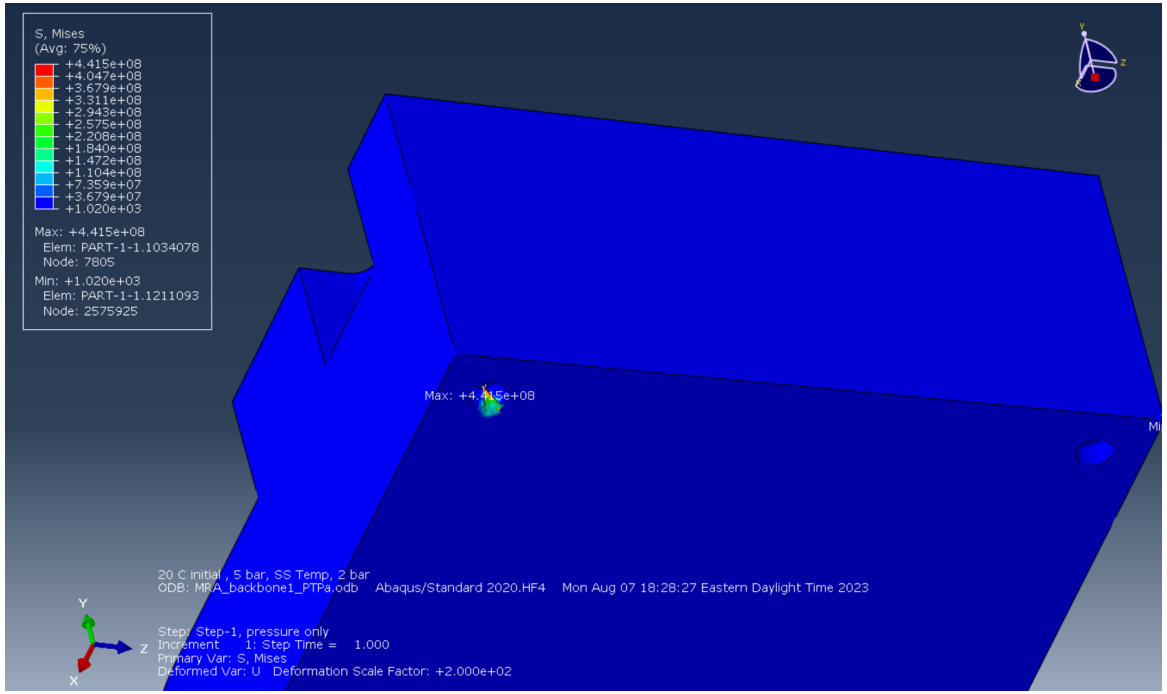


Net body force imposed from open tubes with 5 bar pressure causing displacements to one side

BC node fixed vertically with high local deformation around node



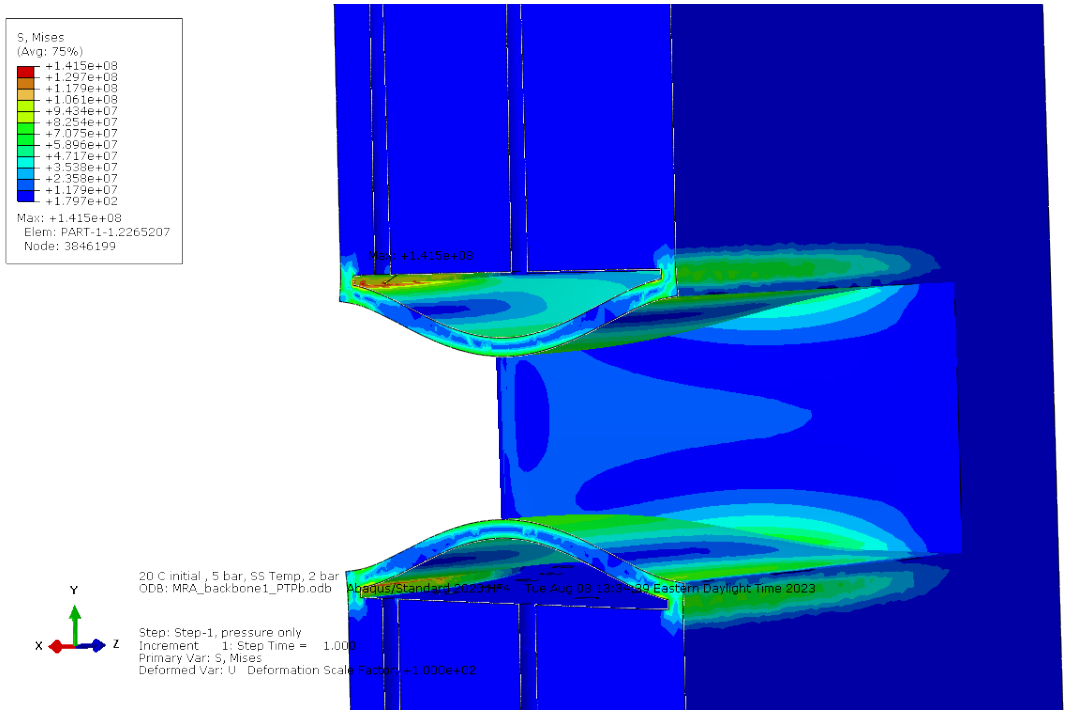
Artificial high stress around fixed node



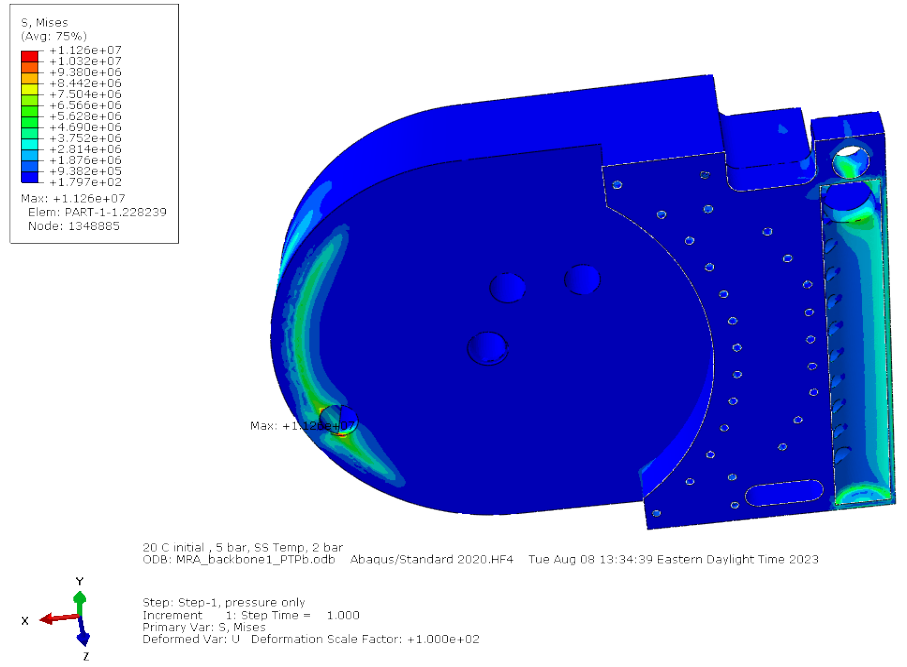
Closed pressure boundaries in full assembly would eliminate the net body forces and these local deformations and peak stresses

5 bar Pressure only results

S Mises 141 MPa peak by thin wall edge



Stresses in Top zone low ~ 11 MPa



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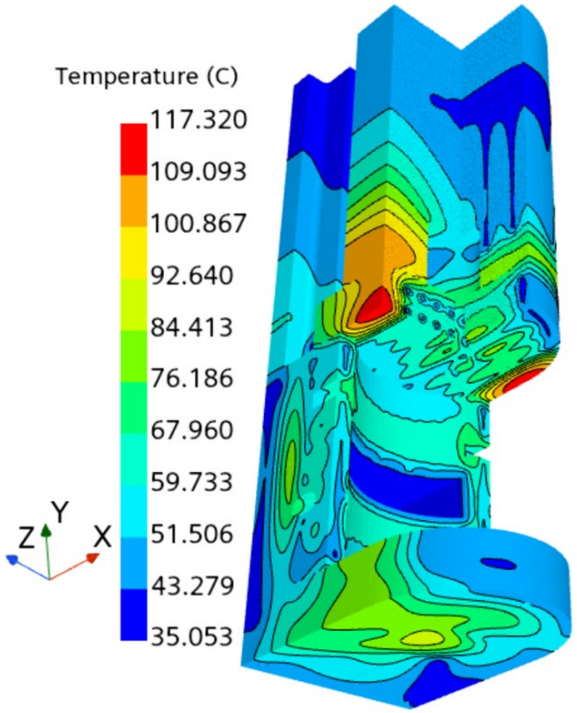
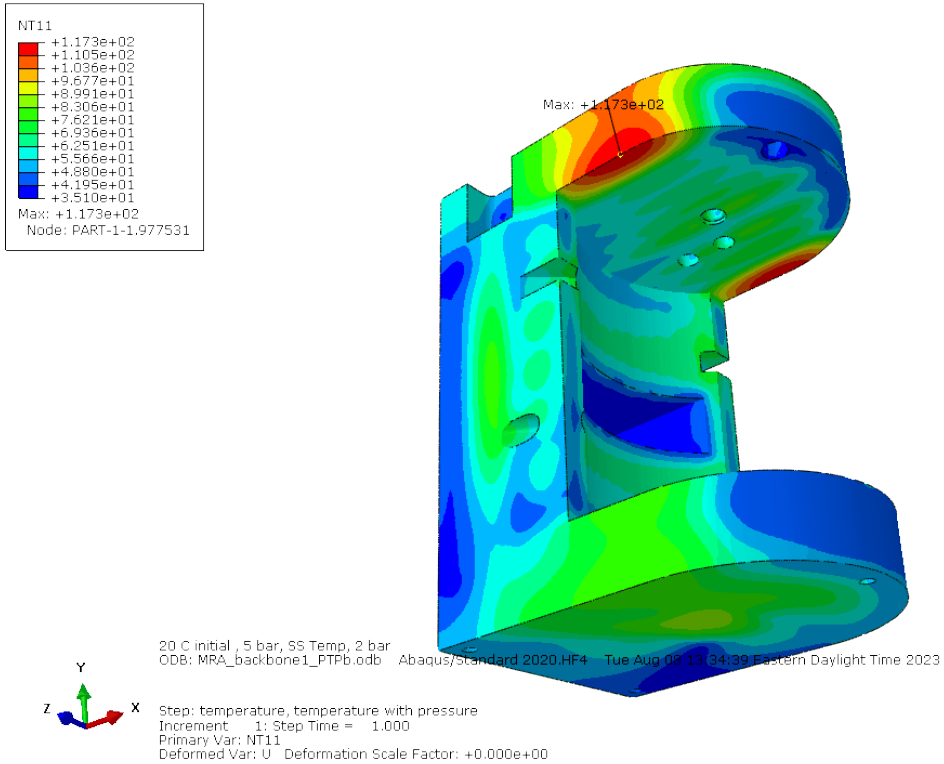
Temperature Profiles

Full Backbone Temperature profile with 0.1mm helium gap



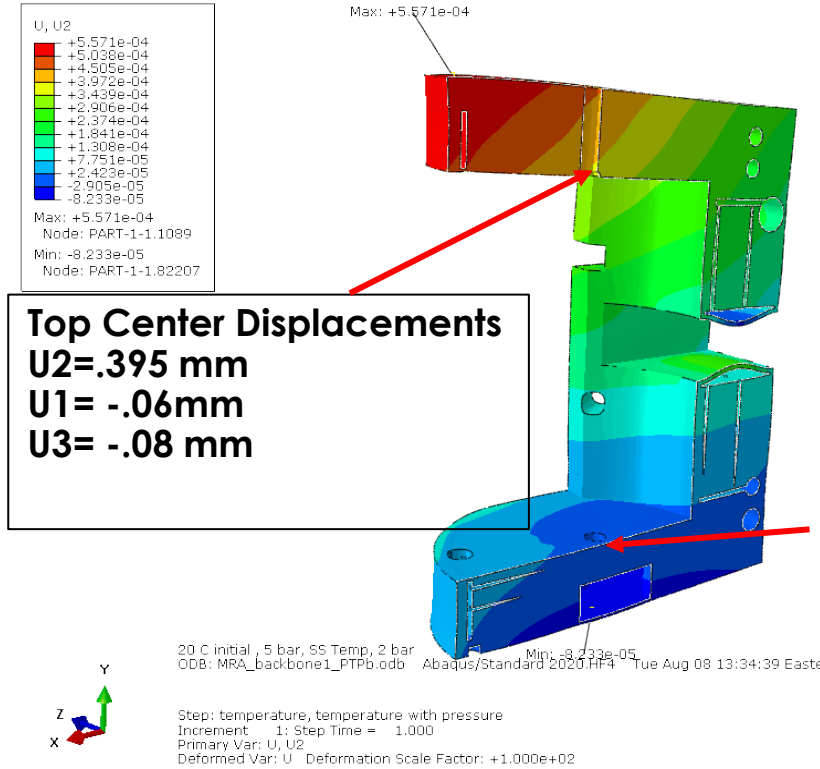
Abaqus Mapped Temperatures – 117 C peak



M.Kao, 7/25/23 CFD Model update

Temperature and 5 bar Pressure

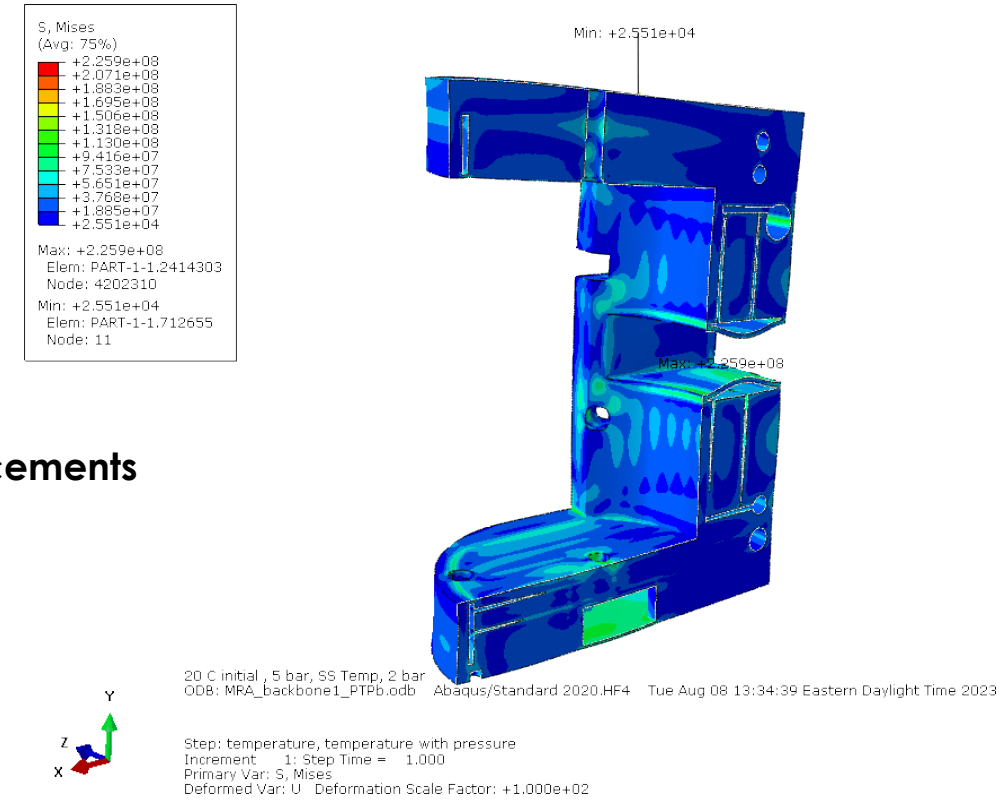
Vertical Displacement < 0.5 mm on axis on upper zone



Top Center Displacements
U2=.395 mm
U1= -.06mm
U3= -.08 mm

Bottom Center Displacements
U2=.009 mm
U1= .02mm
U3= .001 mm

Peak Von Mises peak stress 226 MPa not including distorted area around boundary condition node



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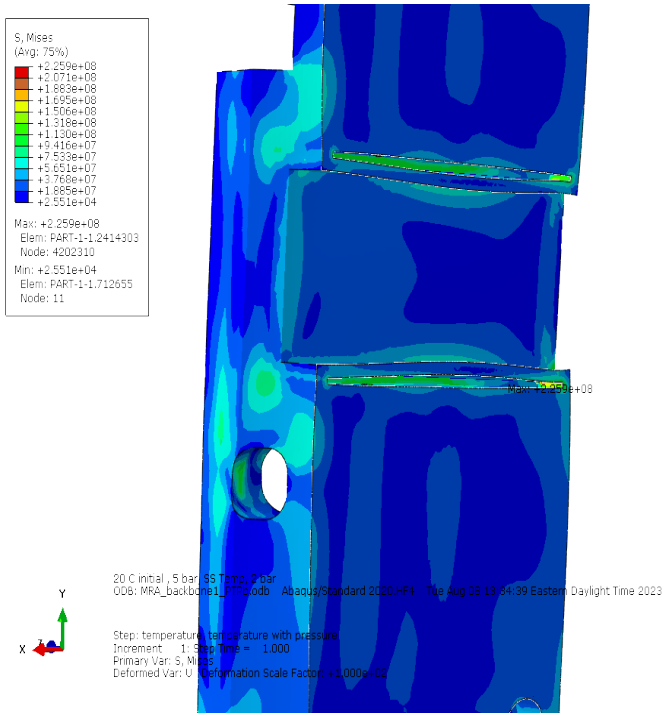
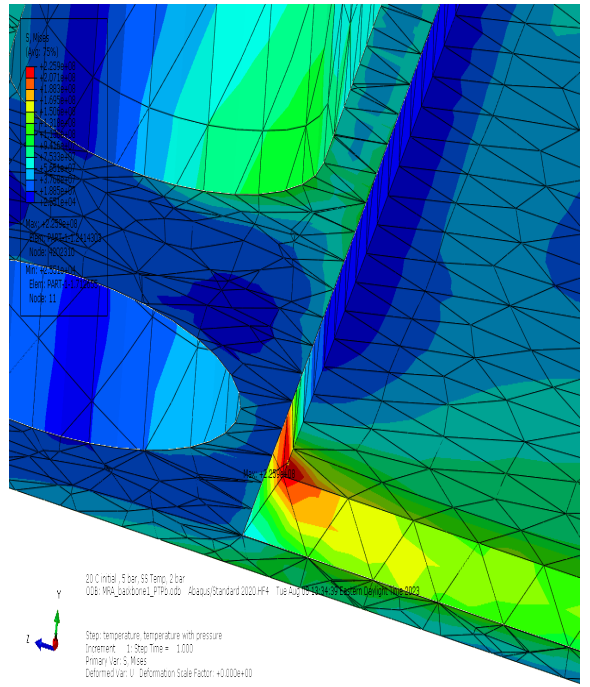
5 bar and Temperature Distribution

226 MPa Peak on corner by proton beam port

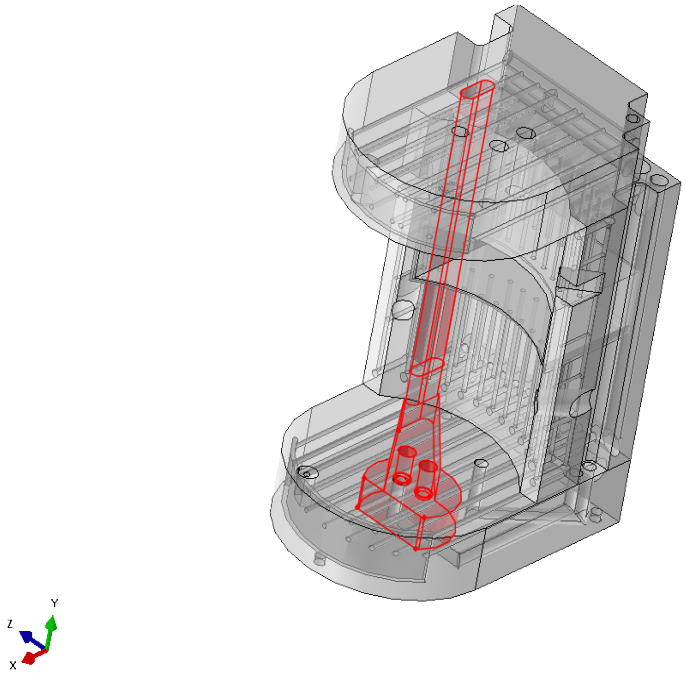


Peak Stress corner location showing mesh

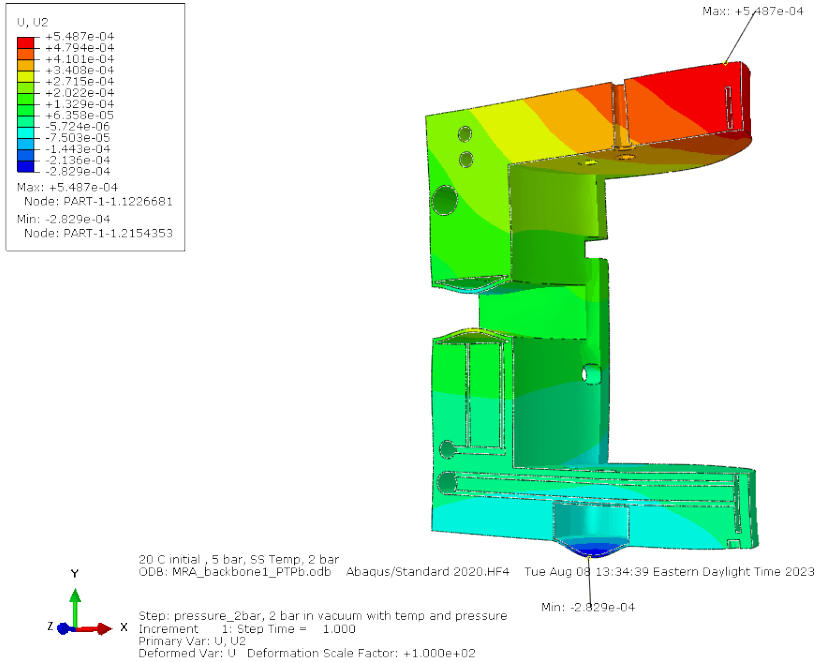


5 bar , Temperature Distribution and 2 bar pressure

Model with additional 2 bar pressure

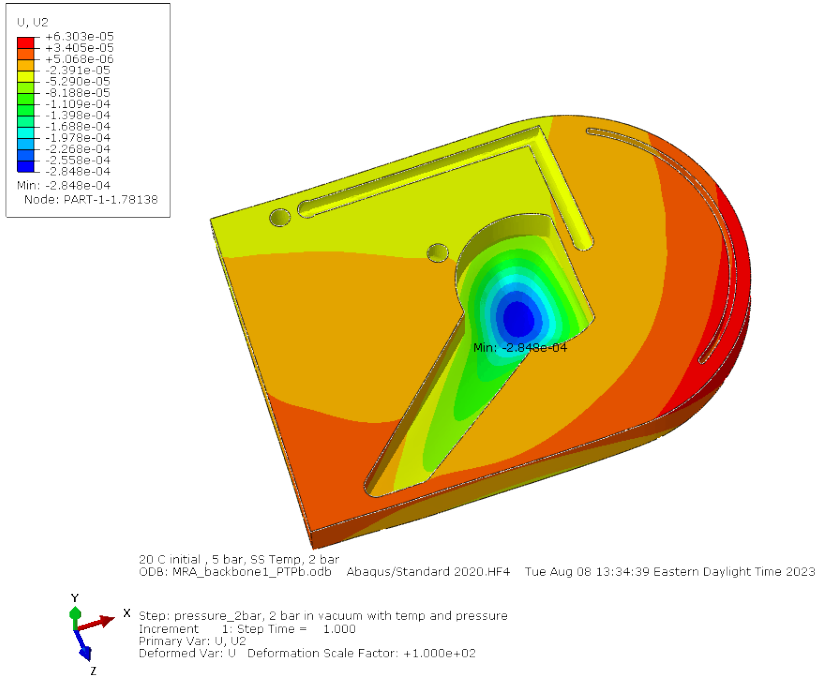


Vertical Displacement – additional 0.28 mm on lower surface moderator zone not changed

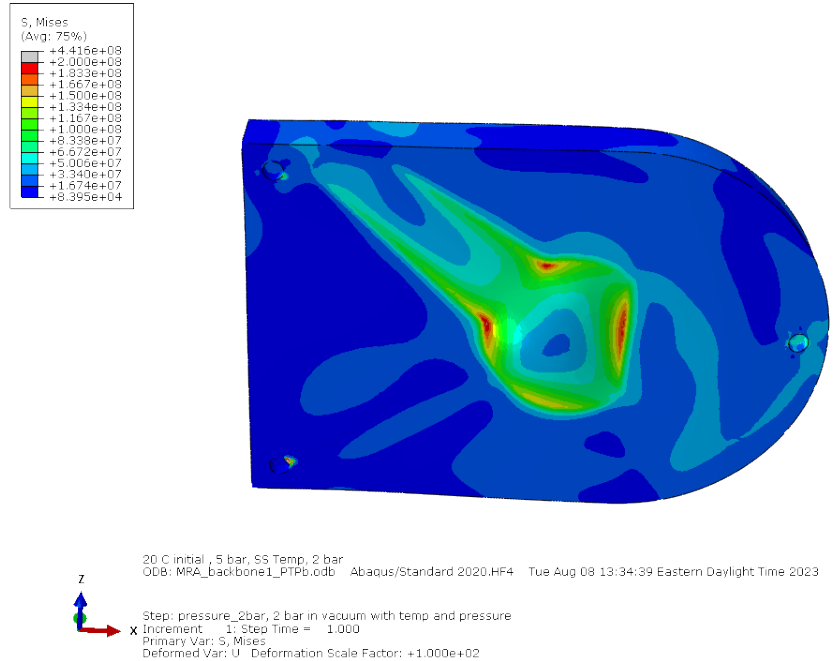


Results with 2 bar pressure added to 5 bar and temperature loads

Internal view of vertical displacement - .28 mm peak



Peak local stress ~ 200 MPa on bottom surface (200 MPa scale)



Results

- Top center reflector vessel mounting surface peak deflection was 0.4 mm on axis with temperature profile and 5 bar internal cooling pressure compared to a limit of 0.5 mm
- Bottom center reflector vessel mounting surface peak deflection was approximately 0.02 mm
- Peak Von Mises stress in thin wall section by beam opening was 141 MPa with 5 bar internal stress
- Peak stress of 226 MPa at localized corner near beam opening
- 2 bar pressure in vacuum region from hydrogen release did not change mounting surface deflection

Summary

- Center mounting surface deflections for normal operation due to water pressure and the temperature profile are below 0.5 mm
- Final design will adjust cooling pattern to reduce rotation of top reflector
- Peak stresses for normal operation are around the thin proton beam channel wall at a sharp corner. Peak model value was 226 MPa but this was at a singularity location and no mesh refinement was attempted.
- Final design is expected to improve regions to reduce high stresses
- The 2 bar pressure excursion stress on the lower surface was approximately 200 MPa and the mounting location deflections were not affected by this pressure release